

# CALCULATED VISCOSITY-DISTANCE DEPENDENCE FOR SOME ACTIVELY FLOWING LAVAS

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The importance of viscosity as a gauge of the various energy and momentum dissipation regimes of lava flows has been realized for a long time. Nevertheless, despite its central role in lava dynamics and kinematics, it remains among the most difficult of flow physical properties to measure in situ during an eruption. Viscosity measurements on active flows are traditionally fraught with local uncertainties due to small-scale anomalies in the flow, as well as with global systematic errors [e.g., 1,2,3]. In addition, the act of making the measurement affects the perceived viscosity. Finally, the presence and evolution of volatiles within the flow during emplacement strongly affects physical properties of the flow, including viscosity. As a result, a posteriori laboratory viscosity measurements made on remelted, nearly volatile-free samples are usually at strong variance with channel-dimension based estimates (e.g., using the Jeffrey's equation) and in-flow field measurements (e.g., using penetrometers or viscometers) made during lava flow emplacement. Thus, only a few systematic studies have been carried out on the viscosity of flows during their emplacement [2,3,4,5,6,7].

Attempts at reconstructing the actual emplacement viscosities of lava flows from their solidified topographic form are difficult. Work in Hawaii by Fink and Zimbelman [8] involved highly detailed topographic surveys of a recent flow from the Puu'Oo vent of Kilauea coupled to reconstructions of emplacement viscosity using a variety of models. They were able to infer a general increase of viscosity with increasing distance from the vent. Recent theoretical work [9] derives characteristic one-dimensional topographic profiles for lava flows based on spatially variable viscosity for both steady-state and time-variable effusion rates. Given the overall topographic profiles coupled to measurements of effusion rate as a function of time, general classes of viscosity-distance functions can be discerned for terrestrial flows. For planetary lava flows, the solution of such boundary-value problems are key to the deciphering of parameters such as initial lava viscosity and initial eruption temperatures [9]. In particular, the estimation of a cessation viscosity (i.e., the viscosity above which a flow cannot move) at the flow front, is a crucial boundary condition on calculations of initial vent parameters and for inferences of flow composition. Thus it would be useful to estimate effective flow viscosities during emplacement as a function of distance and time.

Where data are available on the position of an advancing flow front as a function of time, it is possible to calculate the effective viscosity of the front as a function of distance from the vent, under the assumptions of a steady-state regime (e.g., constant effusion rate, constant source depth, constant initial viscosity). Specifically, the admissible location of the advancing flow front is given by Baloga and Pieri ([9]; equation {9}, p. 9544) as

$$\frac{dL}{dt} = \left[ \frac{g \sin \theta (Q_0/W)^2}{3\nu(L)} \right]^{1/3} \quad (1)$$

Equation (1) provides an alternative to the usual Jeffreys' method of viscosity determination in that if the flow front velocity, slope ( $\theta$ ), average effusion rate ( $Q_0$ ), an width ( $W$ ) are known, the aggregate viscosity ( $\nu(L)$ ) of the flow-front as a function of distance can be calculated. It is precisely this "aggregate viscosity" which reflects the kinematic and dynamic conditions at the distal end of the flow, and which is the key to the interpretation of revealing parameters such as "topographic form factors" [10] for planetary flows.

As an application and test of equation (1), relevant parameters from five recent flows on Mauna Loa and Kilauea [11, 12] were utilized to infer the dynamic structure of their aggregate flow-front viscosity as they advanced, up to cessation. Representative results of these calculations are shown in Figures 1 and 2. Instantaneous velocities were determined from least-square fits to the flow position versus time data. Viscosities were calculated using a measured average effusion rate, a measured initial flow depth and viscosity, and observed width as a function of distance from the vent.

The observed form of the viscosity-distance relation for the five active Hawaiian flows examined appears to be exponential, with a rapid increase just before the flows stopped, as one would expect. Cessation viscosities appear to be on the order of  $10^{11}$ – $10^{13}$  stokes, which is consistent with field estimates of that parameter from another Hawaiian flow (H. Moore, personal communication). Similar calculations (Figure 3) using the traditional Jeffreys' equation (i.e., not taking into account changes in flow width) for the same flows, produce cessation viscosities which appear to be systematically low and do not show the same characteristic viscosity increase corresponding to the stopping of the flow.

An exponential viscosity-distance dependence has been inferred for flows thickening exponentially with downflow distance (e.g., many Hawaiian flows and long flows at Alba Patera, Mars). Results shown here are consistent with such inferences and additionally provide a key boundary condition for modelling the behavior of flow fronts.

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# VISCOSITY-DISTANCE RELATIONS FOR TWO HAWAIIAN LAVA FLOWS

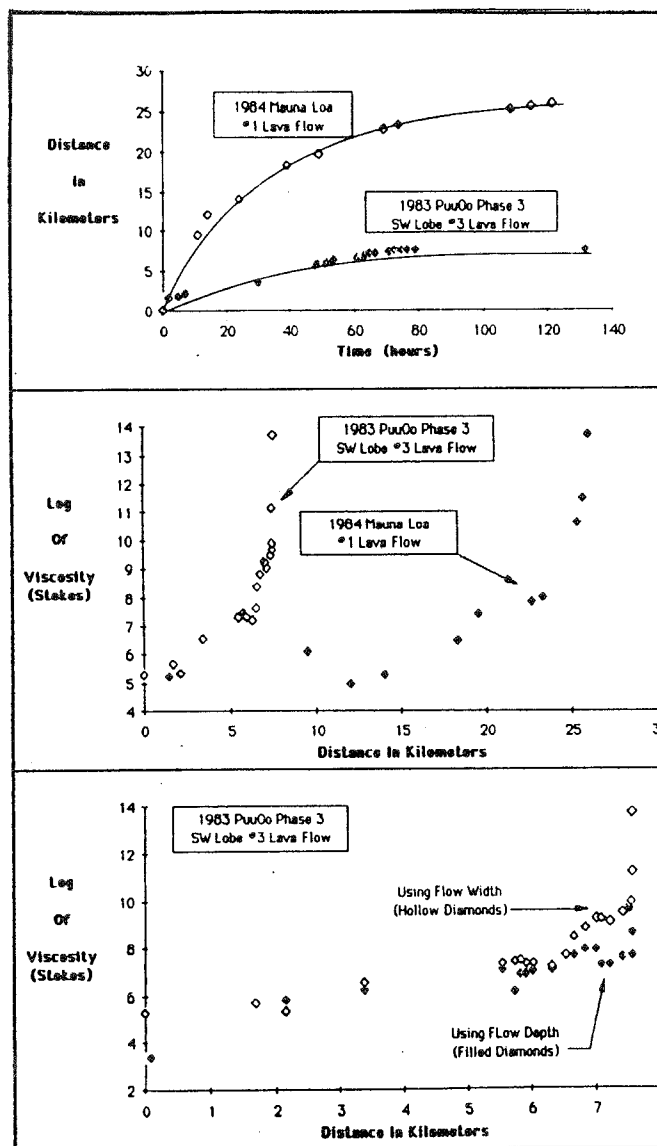


Figure 1. Distance versus time data [11, 12] for two representative Hawaiian lava flows: the 1984 Mauna Loa #1 Flow and the 1983 Puu' Ōo vent Phase 3 (SW Lobe #3) Flow of Kilauea. The solid lines shown represent best-fit arbitrary least squares regressions on the data. Velocity values for the flow were calculated by taking derivatives of the best-fit curves. (Effusion rates for the two flows differed by an order of magnitude [11, 12].)

Figure 2. Viscosity versus distance for the same two flows. Here, both viscosities are calculated using equation (1). Note the strong similarity in forms of the two viscosity-distance curves. These viscosities represent the effective viscosity of the flow front as a function of distance from the vent for an observed average eruption rate. Also note the strong viscosity increase at cessation.

Figure 3. Viscosity calculated (as in Figure 2) using equation (1): (Hollow diamonds), versus viscosity calculated using the standard Jeffreys' formulation ((i.e.,  $\nu = g (\sin\theta) gh^2/3v$ ): filled diamonds). Note the systematic difference between the two calculated curves and the lack of sensitivity in the Jeffreys' calculation to flow cessation.